Network Working Group   O. Gonzalez de Dios, Ed.
Internet-Draft   Telefonica I+D
Intended status: Standards Track   R. Casellas, Ed.
Expires: August 29, 2013   CTTC
                                                           F. Zhang
                                                             Huawei
                                                             X. Fu
                                                               ZTE
                                                      D. Ceccarelli
                                                           Ericsson
                                                         I. Hussain
                                                           Infinera
                                                  February 25, 2013

       **Framework and Requirements for GMPLS based control of Flexi-grid DWDM
                                  networks**
                draft-ogrcetal-ccamp-flexi-grid-fwk-02

Abstract

   This document defines a framework and the associated control plane
   requirements for the GMPLS based control of flexi-grid DWDM networks.
   To allow efficient allocation of optical spectral bandwidth for high
   bit-rate systems, the International Telecommunication Union
   Telecommunication Standardization Sector (ITU-T) has extended the
   recommendations [G.694.1] and [G.872] to include the concept of
   flexible grid: a new DWDM grid has been developed within the ITU-T
   Study Group 15 by defining a set of nominal central frequencies,
   smaller channel spacings and the concept of "frequency slot". In
   such environment, a data plane connection is switched based on
   allocated, variable-sized frequency ranges within the optical
   spectrum.

Status of this Memo

This Internet-Draft will expire on August 29, 2013.

Copyright Notice

Table of Contents

1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Introduction

The term "Flexible grid" (flexi-grid for short) as defined by the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Study Group 15 in the latest version of [G.694.1], refers to the updated set of nominal central frequencies (a frequency grid), channel spacings and optical spectrum management/allocation considerations that have been defined in order to allow an efficient and flexible allocation and configuration of optical spectral bandwidth for high bit-rate systems.

A key concept of flexi-grid is the "frequency slot"; a variable-sized optical frequency range that can be allocated to a data connection. As detailed later in the document, a frequency slot is characterized by its nominal central frequency and its slot width which, as per [G.694.1], is constrained to be a multiple of a given slot width granularity.

Compared to a traditional fixed grid network, which uses fixed size optical spectrum frequency ranges or "frequency slots" with typical channel separations of 50 GHz, a flexible grid network can select its media channels with a more flexible choice of slot widths, allocating as much optical spectrum as required, allowing high bit rate signals (e.g., 400G, 1T or higher) that do not fit in the fixed grid.

From a networking perspective, a flexible grid network is assumed to be a layered network [G.872][G.800] in which the flexi-grid layer (also referred to as the media layer) is the server layer and the OCh Layer (also referred to as the signal layer) is the client layer. In the media layer, switching is based on a frequency slot, and the size of a media channel is given by the properties of the associated frequency slot. In this layered network, the media channel itself can be dimensioned to contain one or more Optical Channels.

As described in [RFC3945], GMPLS extends MPLS from supporting only Packet Switching Capable (PSC) interfaces and switching to also support four new classes of interfaces and switching that include Lambda Switch Capable (LSC).

A Wavelength Switched Optical Network (WSON), addressed in [RFC6163], is a term commonly used to refer to the application/deployment of a

Generalized Multi-Protocol Label Switching (GMPLS)-based control
plane for the control (provisioning/recovery, etc) of a fixed grid
WDM network. [editors' note: we need to think of the relationship of
WSON and OCh switching. Are they equivalent? WSON includes
regeneration, OCh does not? decoupling of lambda/OCh/OCC]

This document defines the framework for a GMPLS-based control of
flexi-grid enabled DWDM networks (in the scope defined by ITU-T
layered Optical Transport Networks [G.872], as well as a set of
associated control plane requirements. An important design
consideration relates to the decoupling of the management of the
optical spectrum resource and the client signals to be transported.
[Editor's note: a point was raised during the meeting that WSON has
not made the separation between Och and Lambda (spectrum and signal
are bundled). The document will consider and evaluate the
relationship later].

[Editors' note: this document will track changes and evolutions of
[G.694.1] [G.872] documents until their final publication. This
document is not expected to become RFC until then.]

[Editor's note: -00 as agreed during IETF83, the consideration of the
concepts of Super-channel (a collection of one or more frequency
slots to be treated as unified entity for management and control
plane) and consequently Contiguous Spectrum Super-channel (a super-
channel with a single frequency slot) and Split-Spectrum super-
channel (a super-channel with multiple frequency slots) is postponed
until the ITU-T data plane includes such physical layer entities,
e.g., an ITU-T contribution exists. ITU-T is still discussing B100G
Architecture]

[Editors' note: -01 this version reflects the agreements made during
IETF84, notably concerning the focus in the media layer, terminology
updates post ITU-T September meeting in Geneva and the deprecation of
the ROADM term, in favor of the more concrete media layer switching
element (media channel matrix).]

[Editors' note: -01 in partial answer to Gert question on the layered
model, [G.872] footnote explains that this separation is necessary to
allow the description of media elements that may act on more than a
single OCh-P signal. See appendix IV within.]

3. Acronyms

FS: Frequency Slot

NCF: Nominal Central Frequency

   OCh: Optical Channel

   OCh-P: Optical Channel Payload

   OCh-O: Optical Channel Overhead

   OCC: Optical Channel Carrier

   SWG: Slot Width Granularity

4. Terminology

   The following is a list of terms (see [G.694.1] and [G.872])
   reproduced here for completeness. [Editors' note: regarding
   wavebands, we agreed NOT to use the term in flexi-grid. The term has
   been used inconsistently in fixed-grid networks and overlaps with the
   definition of frequency slot. If need be, a question will be sent to
   ITU-T asking for clarification regarding wavebands.]

   Where appropriate, this documents also uses terminology and
   lexicography from [RFC4397].

   [Editors' note: *important* these terms are not yet final and they
   may change / be replaced or obsoleted at any time.]

4.1. Frequency Slots

   o Nominal Central Frequency Granularity: 6.25 GHz (note: sometimes
      referred to as 0.00625 THz).

   o Nominal Central Frequency: each of the allowed frequencies as per
      the definition of flexible DWDM grid in [G.694.1]. The set of
      nominal central frequencies can be built using the following
      expression f = 193.1 THz + n x 0.00625 THz, where 193.1 THz is
      ITU-T ''anchor frequency'' for transmission over the C band, n is
      a positive or negative integer including 0.


```
   -5 -4 -3 -2 -1  0  1  2  3  4  5     <- values of n
 ...+--+--+--+--+--+--+--+--+--+--+-
                 ^
                 193.1 THz <- anchor frequency
```


      Figure 1: Anchor frequency and set of nominal central frequencies

   o Slot Width Granularity: 12.5 GHz, as defined in [G.694.1].

   o Slot Width: The slot width determines the "amount" of optical
      spectrum regardless of its actual "position" in the frequency
      axis. A slot width is constrained to be m x SWG (that is, m x
      12.5 GHz), where m is an integer greater than or equal to 1.

   o Frequency Slot: The frequency range allocated to a slot within the
      flexible grid and unavailable to other slots. A frequency slot is
      defined by its nominal central frequency and its slot width.
      Assuming a fixed and known central nominal frequency granularity,
      and assuming a fixed and known slot width granularity, a frequency
      slot is fully characterized by the values of 'n' and 'm'. Note
      that an equivalent characterization of a frequency slot is given
      by the start and end frequencies (i.e., a frequency range) which
      can, in turn, be defined by their respective values of 'n'.

          Frequency Slot 1   Frequency Slot 2
           -------------   -------------------
           | | | |
       -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
     ..--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--...
           -------------   -------------------
               ^   ^
        Central F = 193.1THz   Central F = 193.14375 THz
        Slot width = 25 GHz   Slot width = 37.5 GHz

                    Figure 2: Example Frequency slots

      * The symbol '+' represents the allowed nominal central
         frequencies, the '--' represents the nominal central frequency
         granularity, and the '^' represents the slot nominal central
         frequency. The number on the top of the '+' symbol represents
         the 'n' in the frequency calculation formula. The nominal
         central frequency is 193.1 THz when n equals zero. Note that
         over a single frequency slot, one or multiple Optical Channels
         may be transported.

      * Note that when there are multiple optical signals within
         frequency slot, then each signal still has its own central
         frequency. That is, the term "central frequency" applies to an
         Optical signal and the term "nominal central frequency" applies
         to a frequency slot. In other words, the Frequency Slot
         central frequency is independent of the signals central
         frequencies.

o Effective Frequency Slot: the effective frequency slot of a media
   channel is the common part of the frequency slots along the media
   channel through a particular path through the optical network. It
   is a logical construct derived from the (intersection of)
   frequency slots allocated to each device in the path. The
   effective frequency slot is an attribute of a media channel and,
   being a frequency slot, it is described by its nominal central
   frequency and slot width.

o As an example, if there are two filters having slots with the same
   n but different m, then the common frequency slot has the smaller
   of the two m values. [Editor's note: within the GMPLS label
   swapping paradigm, the switched resource corresponds to the local
   frequency slot defined by the observable filters of the media
   layer switching element. The GMPLS label MUST identify the
   switched resource locally, and (as agreed during IETF84) is
   locally scoped to a link, even if the same frequency slot is
   allocated at all the hops of the path. Note that the requested
   slot width and the finally allocated slot width by a given node
   may be different, e.g., due to restrictions in the slot width
   granularity of the nodes. Due to the symmetric definition of
   frequency slot, allocations seem to be constrained to have the
   same nominal central frequency. It is important to note that if n
   changes along the path, it cannot be guaranteed that there is a
   valid common frequency slot. We must determine if different n's
   are allowed. We need to explain this rationale. e.g. what happens
   when the resulting slot cannot be characterized with n and m, see
   Figure 3 and Figure 4.].

                        Frequency Slot 1

                 | |
        -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
        ..--+--+--+--+--X--+--+--+--+--+--+--+--+--+--+--+--...

                Frequency Slot 2

                 | |
        -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
        ..--+--+--+--+--X--+--+--+--+--+--+--+--+--+--+--+--...

      ===
           Effective Frequency Slot

                 | |
        -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
        ..--+--+--+--+--X--+--+--+--+--+--+--+--+--+--+--+--...
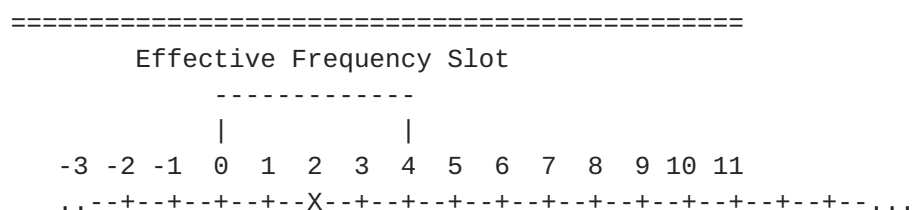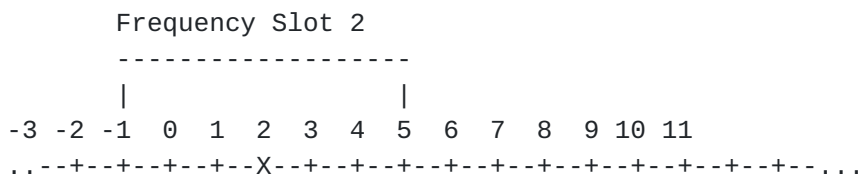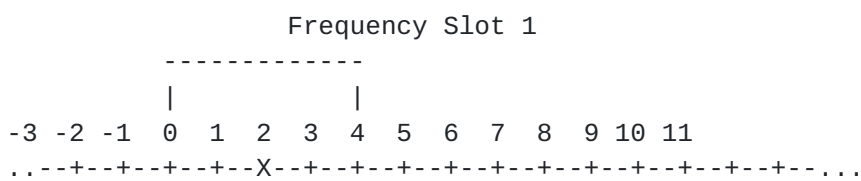
Figure 3: Effective Frequency Slot

```
    Frequency Slot 1
     ------------
      |          |
  -3 -2 -1  0  1  2  3  4  5  6  7  8  9 10 11
.,--+--+--X--+--+--+--+--+--+--+--+--+--+--+--...

        Frequency Slot 2
        ------------------
        |                |
  -3 -2 -1  0  1  2  3  4  5  6  7  8  9 10 11
.,--+--+--+--+--X--+--+--+--+--+--+--+--+--+--...

 =============================================
        Invalid Effective Frequency Slot - (n, m?)
        ----------
        |        |
  -3 -2 -1  0  1  2  3  4  5  6  7  8  9 10 11
.,--+--+--+--+--+--+--+--+--+--+--+--+--+--+--...
```
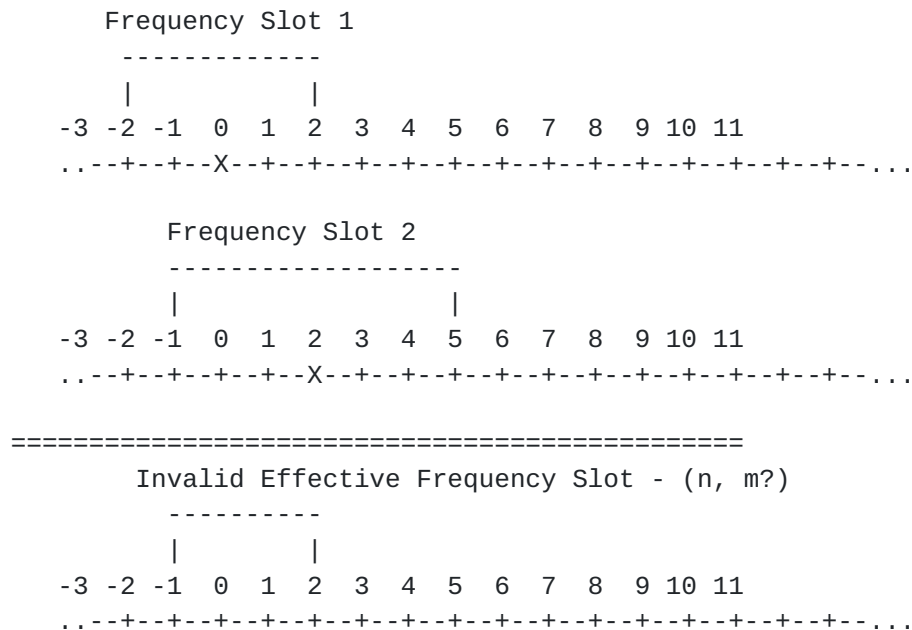
Figure 4: Invalid Effective Frequency Slot

4.2. Media Layer, Elements and Channels

o Media Element: a media element only directs the optical signal or
   affects the properties of an optical signal, it does not modify
   the properties of the information that has been modulated to
   produce the optical signal. Examples of media elements include
   fibers, amplifiers, filters, switching matrices[Note: the data
   plane component of a LSR in the media layer is a media element,
   but not all media elements correspond to data plane nodes in the
   GMPLS network model.

o Media Channel: a media association that represents both the
   topology (i.e., path through the media) and the resource
   (frequency slot) that it occupies. As a topological construct, it
   represents a (effective) frequency slot supported by a
   concatenation of media elements (fibers, amplifiers, filters,
   switching matrices...). This term is used to identify the end-to-
   end physical layer entity with its corresponding (one or more)
   frequency slots local at each link filters.

o Network Media Channel: a media channel (media association) that
   supports a single OCh-P network connection. It represents the

      concatenation of all media elements between an OCh-P source and an
      OCh-P sink. [TODO: |Malcolm| explain the use case rationale to
      support a hierarchy of media channels, where a media channel acts
      as "pipe" for one or more network media channels and they are both
      separate entities (IETF84). This may be tied to the concept of a
      "waveband" or express channel, as stated in [G.872] footnote 4.]

   o OCh-P Frequency Slot: The spectrum allocated to a single OCh
      signal supported on a Network Media Channel.

   Note that by definition a network media channel only supports a
   single OCh-P network connection, but the architecture is flexible
   enough to support the case where a single Optical Channel Payload
   (OCh-P) is transported over multiple (N) network media channels (see
   Figure 5) which are non-necessarily adjacent (e.g., there may not
   exist an equivalent network media channel that can be represented as
   the union of media channels with a single, valid equivalent frequency
   slot). Whether a single OCh-P is transported over just one or more
   network media channels is an aspect that corresponds to the mapping
   of the signal layer to the media layer.

                          OCh-P   Signal Layer
                  +--------X----------+
                   /   \   Media Layer
                  /   \
        Network Media Channel #1   ...   Network Media Channel #N
        +------------O-----------+   +----------X-----------+
        | | | |
...   +---+---+---+---+---+---+---+---+---+---+---+--+---+---+---+---+---+---...

       Figure 5: A single OCh-P transported over multiple network media
                                 channels

4.3. Media Layer Switching

   [Editors' note: we are not discarding O/E/O. If defined in a ITU-T
   network reference model with trail/terminations, considering optical
   channels i.e. with well-defined interfaces, reference points, and
   architectures. The implications of O/E/O will be also addressed once
   we have another context that includes them. In OTN from an OCh point
   of view end to end means from transponder to transponder, so if there
   is a 3R from ingress to egress there are 2 OCh which can have
   different 'n' and 'm'].

   o Media Channel Matrixes: the media channel matrix provides flexible
      connectivity for the media channels. That is, it represents a

point of flexibility where relationships between the media ports
at the edge of a media channel matrix may be created and broken.
The relationship between these ports is called a matrix channel.
(Network) Media Channels are switched in a Media Channel Matrix.

In summary, the concept of frequency slot is a logical abstraction
that represents a frequency range while the media layer represents
the underlying media support. Media Channels are media associations,
characterized by their (effective) frequency slot, respectively; and
media channels are switched in media channel matrixes. In Figure 6 ,
a Media Channel has been configured and dimensioned to support two
OCh-P, each transported in its own OCh-P frequency slot.


```
                       Media Channel Frequency Slot
      +--------------------------------X-------------------------------+
      |                                                                |
      |         OCh-P Frequency Slot           OCh-P Frequency Slot    |
      |    +------------X-----------+        +----------X-----------+   |
      |    |        OCh-P           |        |        OCh-P         |   |
      |    |           o            |        |           o          |   |
      |    |           |            |        |           |          |   |
     -4  -3  -2  -1   0   1   2   3   4   5   6   7  8   9  10  11  12
...    +---+---+---+---+---+---+---+---+---+---+---+--+---+---+---+---+---...

...       <- Network Media Channel->     <- Network Media Channel->

...   <----------------------- Media Channel ----------------------->

      X - Frequency Slot Central Frequency

      o - signal central frequency
```
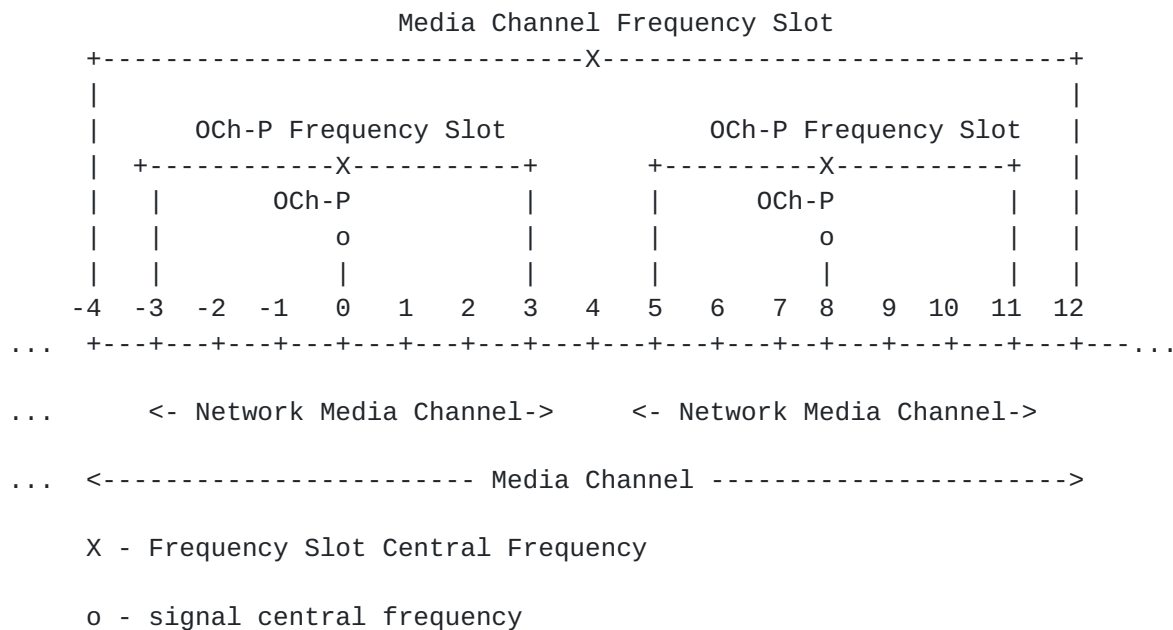
         Figure 6: Example of Media Channel / Network Media Channels and
                         associated frequency slots

4.4. Control Plane Terms

The following terms are defined in the scope of a GMPLS control
plane.

o SSON: Spectrum-Switched Optical Network. Refers to an optical
   network in which a LSP is switched based on an frequency slot of a
   variable slot width of a media channel, rather than based on a
   fixed grid and fixed slot width. Please note that a Wavelength
   Switched Optical Network (WSON) can be seen as a particular case
   of SSON in which all slot widths are equal and depend on the used

channel spacing.

o RSA: Routing and Spectrum Assignment. As opposed to the typical
   Routing and Wavelength Assignment (RWA) problem of traditional WDM
   networks, the flexibility in SSON leads to spectral contiguous
   constraint, which means that when assigning the spectral resources
   to single connections, the resources assigned to them must be
   contiguous over the entire connections in the spectrum domain.

5. DWDM flexi-grid enabled network element models

Similar to fixed grid networks, a flexible grid network is also
constructed from subsystems that include Wavelength Division
Multiplexing (WDM) links, tunable transmitters and receivers, i.e,
media elements including media layer switching elements (media
matrices), as well as electro-optical network elements, all of them
with flexible grid characteristics.

[Editors' Note: In the scope of this document, and despite is
informal use, the term Reconfigurable Optical Add / Drop Multiplexer,
(ROADM) is avoided, in favor on media matrix. This avoid ambiguity.
A ROADM can be implemented in terms on media matrices.
Informationally, this document may provide an appendix on possible
implementations of flexi-ROADMs in terms of media layer switching
elements or matrices. XF: Whether ROADM is used or not doesn't
matter with GMPLS Control Plane. I suggest to delete this statement.
We may check G.798. Likewise, modeling of filters is out of scope of
the current document IETF84, and is also considered implementation
specific.]

As stated in [G.694.1] the flexible DWDM grid defined in Clause 7 has
a nominal central frequency granularity of 6.25 GHz and a slot width
granularity of 12.5 GHz. However, devices or applications that make
use of the flexible grid may not be capable of supporting every
possible slot width or position. In other words, applications may be
defined where only a subset of the possible slot widths and positions
are required to be supported. For example, an application could be
defined where the nominal central frequency granularity is 12.5 GHz
(by only requiring values of n that are even) and that only requires
slot widths as a multiple of 25 GHz (by only requiring values of m
that are even).

5.1. Network element constraints

[TODO: section needs to be rewritten, remove redundancy].

Optical transmitters/receivers may have different tunability

constraints, and media channel matrixes may have switching
restrictions. Additionally, a key feature of their implementation is
their highly asymmetric switching capability which is described in
[RFC6163] in detail. Media matrices include line side ports which
are connected to DWDM links and tributary side input/output ports
which can be connected to transmitters/receivers.

A set of common constraints can be defined:

o The minimum and maximum slot width.

o Granularity: the optical hardware may not be able to select
   parameters with the lowest granularityy (e.g. 6.25 GHz for nominal
   central frequencies or 12.5 GHz for slot width granularity).

o Available frequency ranges: the set or union of frequency ranges
   that are not allocated (i.e. available). The relative grouping
   and distribution of available frequency ranges in a fiber is
   usually referred to as ''fragmentation''.

o Available slot width ranges: the set or union of slot width ranges
   supported by media matrices. It includes the following
   information.

   * Slot width threshold: the minimum and maximum Slot Width
      supported by the media matrix. For example, the slot width can
      be from 50GHz to 200GHz.

   * Step granularity: the minimum step by which the optical filter
      bandwidth of the media matrix can be increased or decreased.
      This parameter is typically equal to slot width granularity
      (i.e. 12.5GHz) or integer multiples of 12.5GHz.

[Editor's note: different configurations such as C/CD/CDC will be
added later. This section should state specifics to media channel
matrices, ROADM models need to be moved to an appendix].

6. Layered Network Model

This section presents an overview of the OCh / flexi-grid layered
network model defined by ITU-T. [Editors' note: OTN hierarchy is not
fully covered. It is important to understand, where the FSC sits in
the OTN hierarchy. This is also important from control plane
perspective as this layer becomes the connection end points of
optical layer service].

```
 OCh AP                      Trail (OCh)                      OCh AP
  O- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - O
  |                                                              |
 --- OCh-P                                            OCh-P ---
 \ / source                                           sink  \ /
  +                                                            +
  | OCh-P              OCh-P Network Connection         OCh-P |
  O TCP - - - - - - - - - - - - - - - - - - - - - - - - -TCP O
  |                                                              |
  |Channel Port          Network Media Channel       Channel Port |
  O - - - - - - - - - - - - - - - - - - - - - - - - - - - - - O
  |                                                              |
+--------+              +-----------+              +----------+
|  \ (1) |  OCh-P LC     |   (1)    |  OCh-P LC     |   (1)  / |
|   \----|---------------|----------|---------------|-------/  |
+--------+ Link Channel  +-----------+  Link Channel  +----------+
Media Channel           Media Channel               Media Channel
  Matrix                  Matrix                       Matrix
```
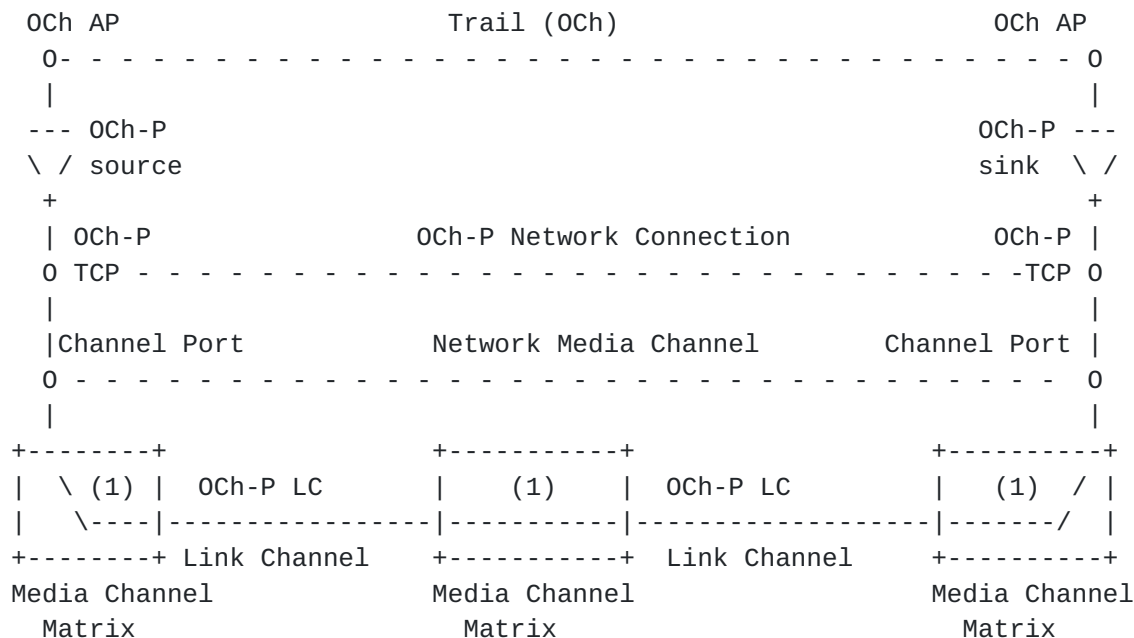
(1) - Matrix Channel

                Figure 7: Layered Network Model according to G.805

   [Editors' note: we are replicating the figure here for reference,
   until the ITU-T document is official.

7. GMPLS applicability

   The goal of this section is to provide an insight of the application
   of GMPLS to flexi-grid networks, while specific requirements are
   covered in the next section. The present framework is aimed at
   controlling the so called media layer within the OTN hierarchy.
   Specifically, the GMPLS control of the media layer deals with the
   establishment of media channels, which are switched in media channel
   matrixes. GMPLS labels locally represent the media channel and its
   associated frequency slot. [Editors'note: As agreed during IETF84,
   current focus is on the media layer.]

   Also, this sections provides a mapping of the mapping ITU-T G.872
   architectural aspects to GMPLS/Control plane terms, and see the
   relationship between the architectural concept/construct of media
   channel and its control plane representations (e.g. as a TE link).

7.1. Considerations on TE Links

   From a theoretical / abstract point of view, a fiber can be modeled
   has having a frequency slot that ranges from (-inf, +inf). This

representation helps understand the relationship between frequency
slots / ranges.

The frequency slot is a local concept that applies locally to a
component / element. When applied to a media channel, we are
referring to its effective frequency slot as defined in [G.872].

The association of a filter, a fiber and a filter is a media channel
in its most basic form, which from the control plane perspective may
modeled as a (physical) TE-link with a contiguous optical spectrum at
start of day. A means to represent this is that the portion of
spectrum available at time t0 depends on which filters are placed at
the ends of the fiber and how they have been configured. Once
filters are placed we have the one hop media channel. In practical
terms, associating a fiber with the terminating filters determines
the usable optical spetrum.

```
----------------+                        +----------------+
                |                        |
    +--------+                        +--------+
    |        |                        |        | +---------
 ---o|        |    ============================    o--|
    |        |    =            Fiber              |        | | --\  /--
 ---o|        |    =                               |        o--|    \/
    |        |    =                               |        | |    /\
 ---o|        |    ============================    o--| --/  \--
    | Filter |                        | Filter |  |
    |        |                        |        | +---------
    +--------+                        +--------+
                |                        |
    |---------- Basic Media Channel   ---------|
----------------+                        +----------------+


    --------+                        +--------+
        |----------------------------------------|
    LSR    |                 TE link              | LSR
        |----------------------------------------|
    +--------+                        +--------+
```

Figure 8: (Basic) Media channel and TE link

Additionally, when a cross-connect for a specific frequency slot is
considered, the underlying media support is still a media channel,
augmented, so to speak, with a bigger association of media elements

and a resulting effective slot. When this media channel is the
result of the association of basic media channels and media layer
matrix cross-connects, this architectural construct can be
represented as / corresponds to a Label Switched Path (LSP) from a
control plane perspective. In other words, It is possible to
"concatenate" several media channels (e.g. Patch on intermediate
nodes) to create a single media channel.

```
------------+      +-------------------------------+      +----------
         |      |                               |      |
   +------+      +------+                 +------+      +------+
   |      |      |      | +----------+    |      |      |      |
 ---o|      ========    o---|          |---o    ========      o--
   |      | Fiber |      |    | --\  /-- |    |    | Fiber |      |
 ---o|      |      |    o---|    \/     |---o    |      |      o--
   |      |      |      |    | |   /\    |    |    |      |      |
 ---o|      ========    o---***********|---o    ========      o--
   |Filter|      |Filter|   |          |    |Filter|      |Filter|
   |      |      |      |   |          |    |      |      |      |
   +------+      +------+                 +------+      +------+
         |      |                               |      |
      <- Basic Media ->     <- Matrix ->         <- Basic Media->
         |Channel|          Channel              |Channel|
------------+      +-------------------------------+      +----------

      <-------------------- Media Channel ----------------->

   -----+      +---------------+              +-------
      |------------------|              |------------------|
   LSR |      TE link    |     LSR      | TE link          | LSR
      |------------------|              |------------------|
   -----+      +---------------+              +-------
```
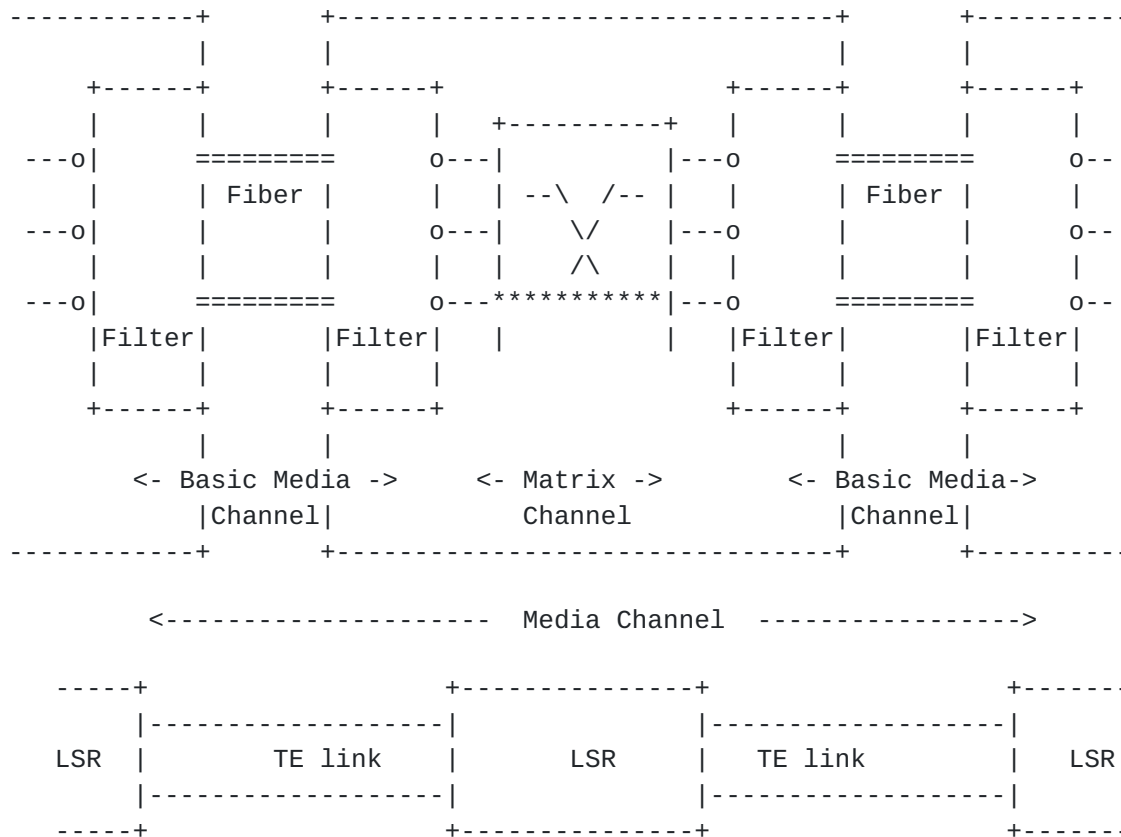
Figure 9: Extended Media Channel

Additionally, if appropriate, it can also be represented as a TE link
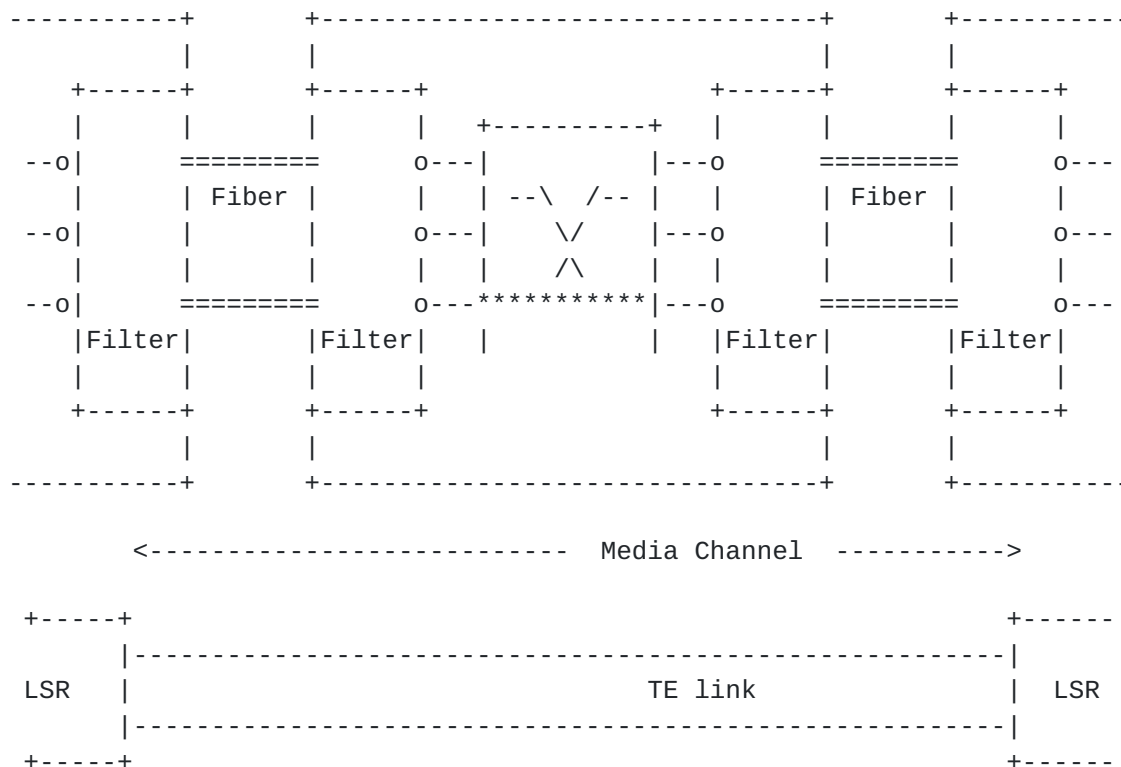or Forwarding Adjacency (FA), augmenting the control plane network
model.

```
-----------+      +-------------------------------+       +-----------
           |      |                               |       |
   +------+        +------+                         +------+       +------+
   |      |        |      |    +----------+   |      |       |      |
 --o|      =========    o---|          |---o   =========     o---
   |     | Fiber |     |    | | --\  /-- |   |     | Fiber |     |
 --o|      |      |     o---|    \/    |---o   |      |      |     o---
   |     |       |     |    | |  /\    |   |     |      |     |
 --o|      =========    o---***********|---o   =========     o---
    |Filter|        |Filter|   |          |  |Filter|       |Filter|
    |      |        |      |   |          |  |      |       |      |
    +------+        +------+                    +------+       +------+
           |      |                               |       |
-----------+      +-------------------------------+       +-----------


       <-------------------------- Media Channel  ----------->

   +-----+                                                  +------
       |----------------------------------------------------------|
   LSR   |                              TE link                | LSR
       |----------------------------------------------------------|
   +-----+                                                  +------
```

                   Figure 10: Extended Media Channel / TE Link / FA

7.2. Considerations on Labeled Switched Path (LSP) in Flexi-grid

   The flexi-grid LSP is seen as a control plane representation of a
   media channel. Since network media channels are media channels, an
   LSP may also be the control plane representation of a network media
   channel, in a particular context. From a control plane perspective,
   the main difference (regardless of the actual effective frequency
   slot which may be dimensioned arbitrarily) is that the LSP that
   represents a network media channel also includes the endpoints
   (transceivers) , including the cross-connects at the ingress / egress
   nodes. The ports towards the client can still be represented as
   interfaces from the control plane perspective.

   Figure 11 describes an LSP routed along 3 nodes. The LSP is
   terminated before the optical matrix of the ingress and egress nodes
   and can represent a Media Channel. This case does NOT (and cannot)
   represent a network media channel as it does not include (and cannot
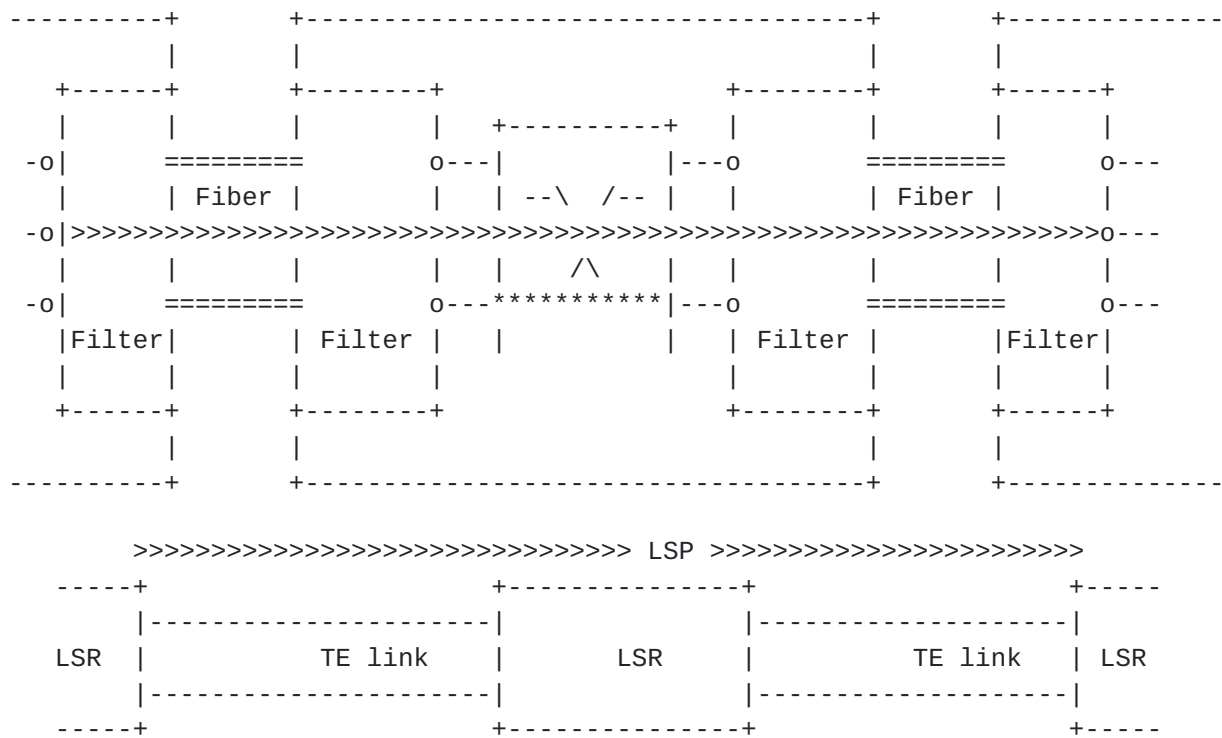   include) the transceivers.

```
----------+       +------------------------------------+       +--------------
          |       |                                    |       |
  +------+         +--------+                  +--------+       +------+
  |      |         |        |    +----------+  |        |       |      |    |
 -o|        ========       o---|          |---o        ========       o---
  |      | Fiber |         |    | --\  /-- |  |       | Fiber |       |
 -o|>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>o---
  |      |        |         |    |   /\     |  |        |       |      |    |
 -o|        ========       o---***********|---o        ========       o---
  |Filter|         | Filter |    |          |  | Filter |       |Filter|
  |      |        |         |    |          |  |        |       |      |    |
  +------+         +--------+                  +--------+       +------+
          |       |                                    |       |
----------+       +------------------------------------+       +--------------


        >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>> LSP >>>>>>>>>>>>>>>>>>>>>>>>>>>
  -----+                        +---------------+                   +-----
       |---------------------|                  |-------------------|
  LSR  |          TE link    |       LSR        |        TE link    | LSR
       |---------------------|                  |-------------------|
  -----+                        +---------------+                   +-----
```

   Figure 11: Flex-grid LSP representing a media channel that starts at
    the filter of the outgoing interface of the ingress LSR and ends at
          the filter of the incoming interface of the egress LSR

   In Figure 12 a Network Media Channel is represented as terminated at
   the DWDM side of the transponder, this is commonly named as OCh-trail
   connection.

```
 |----------------------- Network Media Channel -------------------------|

      +------------------------+              +------------------------+
      |                        |              |                        |
      +------+        +------+  |              +------+        +------+  |
      |      | +------+ |     |            |      | +------+ |     |OCh-P
OCh-P|   o-|        |-o    |    +-----+   |      o-|        |-o   |sink
 src |   | |        | |  =====+-+ +-+=====|      | |        | |    O---|R
T|***o******o*******************************************************************
      |   | | \  / | |      | | | |        |   | | \  / | |       |
      |   o-|  \/  |-o   =====| | | |=====|      o-|  \/  |-o      |
      |   | |  /\  | |      | +-+ +-+      |   | |  /\  | |       |
      |   o-| /  \ |-o      | | \/ |       |   o-| /  \ |-o       |
      |Filter| |     |Filter| | /\ |       |Filter| |     |Filter|
      +------+ |     | +------+  +------+   +------+ |     | +------+
      |        |     |        |          |        |     |        |
      +------------------------+          +------------------------+
                                    LSP
 <----------------------------------------------------------------------->

                                    LSP
   <----------------------------------------------------------------------->
      +-----+                +--------+                +-----+
   o--- |     |----------------------|        |------------------|     |---o
      | LSR |     TE link          | LSR  |     TE link        | LSR |
      |     |----------------------|        |------------------|     |
      +-----+                +--------+                +-----+
```
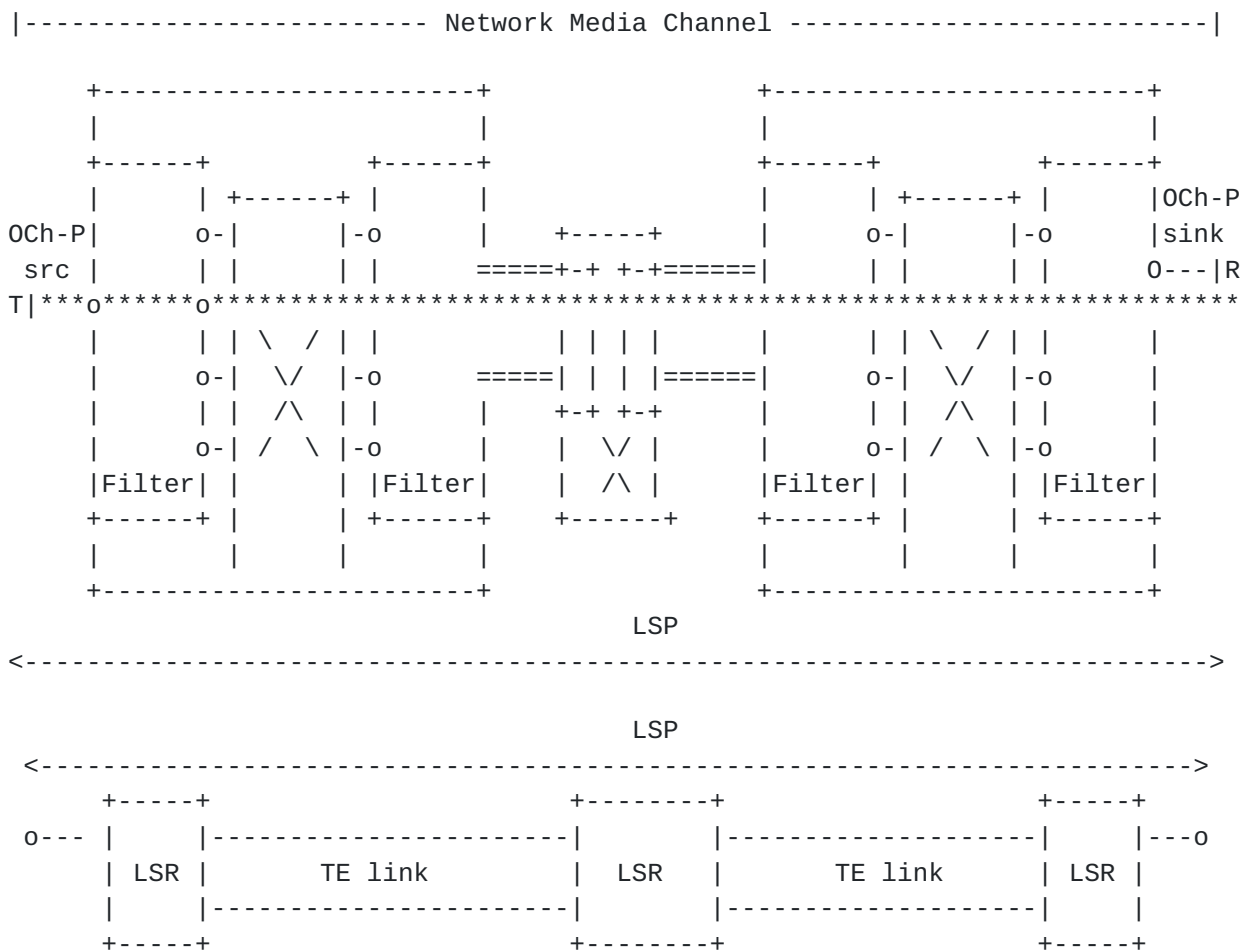
            Figure 12: LSP representing a network media channel (OCh-Trail)

    In a third case, a Network Media Channel terminated on the Filter
    ports of the Ingress and Egress nodes. This is named in G.872 as
    OCh-NC (we need to discuss the implications, if any, once modeled at
    the control plane level of models B and C).

```
    |---------------------- Network Media Channel -------------------|

    +-----------------------+          +-----------------------+
    +------+          +------+          +------+          +------+
    |      | +-----+  |      |          |      | +------+ |      |
    |    o-|      |-o  |    +------+     |    o-|      |-o      |
    |    | |      | |  =====+-+  +-+=====|    | |      | |  O---|R
T|--o******o********************************************************o*****
    |    | |\  / | |        | | | |      |    | |\  / | |          |
    |    o-| \/  |-o  =====| |  | |=====  o-|  \/  |-o          |
    |    | | /\  | |        | +-+  +-+     |    | | /\  | |          |
    |    o-| / \ |-o  |     | | \/  |      |    o-| / \ |-o          |
    |Filter| |     | |Filter|  |  /\  |  |Filter| |     | |Filter|
    +------+ |     | +------+  +------+   +------+ |     | +------+
    |        |     |        |          |        |     |        |
    +-----------------------+          +-----------------------+
    <---------------------------------------------------------------->
                                LSP


                                LSP
    <---------------------------------------------------------------->
    +-----+                    +--------+                    +-----+
o---|     |--------------------|        |--------------------|     |---o
    | LSR |       TE link      |  LSR   |       TE link      | LSR |
    |     |--------------------|        |--------------------|     |
    +-----+                    +--------+                    +-----+
```
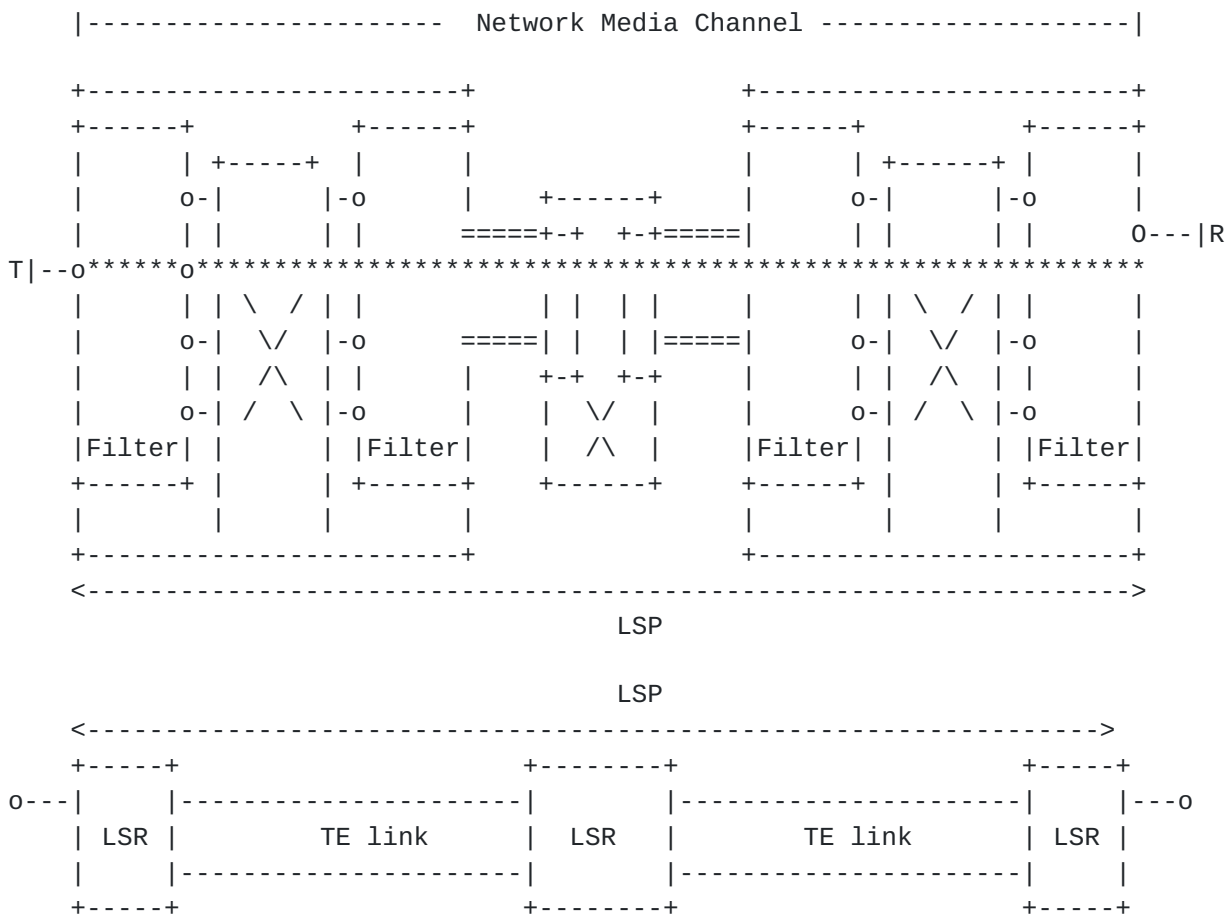
          Figure 13: LSP representing a network media channel (OCh-P NC)

     [Note: not clear the difference, from a control plane perspective, of
     figs Figure 12 and Figure 13.]

     Applying the notion of hierarchy at the media layer, by using the LSP
     as a FA, the media channel created can support multiple (sub) media
     channels. [Editot note : a specific behavior related to Hierarchies
     will be verified at a later point in time].

```
+--------------+                        +--------------+
|    OCh-P     |            TE          |    OCh-P     | Virtual TE
|              |            link        |              |    link
|    Matrix    |o- - - - - - - - - - - o|    Matrix    |o- - - - - -
+--------------+                        +--------------+
               |          +---------+          |
               |          |  Media  |          |
               |o------|  Channel  |---------o|
               |          |         |
               |          |  Matrix |
                          +---------+
```
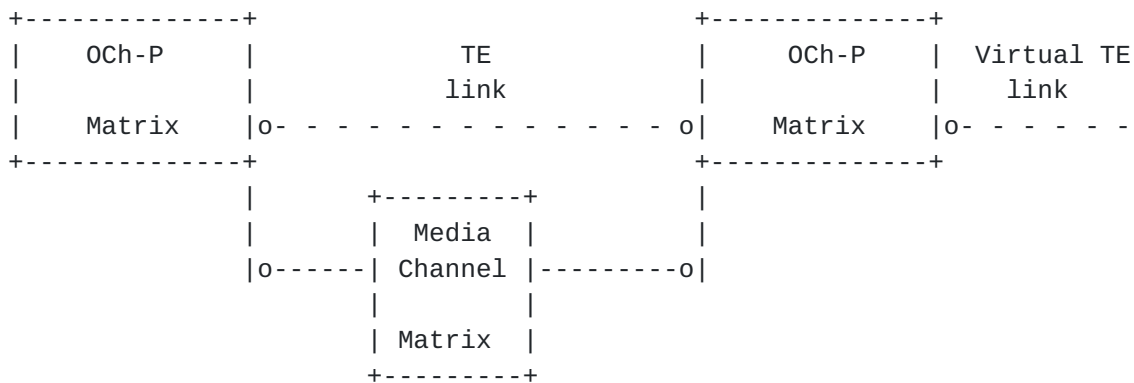
           Figure 14: MRN/MLN topology view with TE link / FA

   Note that there is only one media layer switch matrix (one
   implementation is FlexGrid ROADM) in SSON, while "signal layer LSP is
   mainly for the purpose of management and control of individual
   optical signal". Signal layer LSPs (OChs) with the same attributions
   (such as source and destination) could be grouped into one media-
   layer LSP (media channel), which has advantages in spectral
   efficiency (reduce guard band between adjacent OChs in one FSC) and
   LSP management. However, assuming some network elements indeed
   perform signal layer switch in SSON, there must be enough guard band
   between adjacent OChs in one media channel, in order to compensate
   filter concatenation effect and other effects caused by signal layer
   switching elements. In such condition, the separation of signal
   layer from media layer cannot bring any benefit in spectral
   efficiency and in other aspects, but make the network switch and
   control more complex. If two OChs must switch to different ports, it
   is better to carry them by diferent FSCs and the media layer switch
   is enough in this scenario.

8. Control Plane Requirements

   [Editor's note: The considered topology view is a layered network, in
   which the media layer corresponds to the server layer (flexigrid) and
   the signal layer corresponds to the client layer (Och). This data
   plane modeling considers the flexigrid and the OCh as separate
   layers, However, this has implications on the interop/interworking
   with WSON and OCh switching. We need to manage a MRN for OCh and
   stitching for WSON? In other words, a key part of the fwk is to
   define how can we have MRN/MLN hierarchical relationship with Och/FS
   and yet stitching 1:1 between WSON and SSON? In this line: how does
   OCh switching and WSON relate, actually?]

   [Editor's note: formal requirements such as noted in the comments

will be added in a later version of the document].

The data plane model decouples media and signal. The data plane
definition relative to the the signal mapping are still ongoing.
Until they are closed, the Control Plane considered is based on a
MRN/MLN network in which the Control Plane differentiates signal LSPs
and media LSPs. This will be revised when the data plane definition
are finalized.

The signal does impose restriction on the flexi-LS by constraining
the effective frequency slot. The central frequency of each hop
should be same along end-to-end media or signal LSP because of
Spectrum Continuity Constraint. [Editors Note: the effective
frequency slot should fit, which clause mandate that the central
frequency is the same ??] Otherwise some nodes need to conver the
central frequency along media or signal LSP.

8.1. Media Layer Resource Allocation considerations

[Editors' note: preliminary text based on IETF85 side-meeting
minutes]

A media channel has an associated effective frequency slot. From the
perspective of network control and management, this effective slot is
seen as the "usable" frequency slot end to end. The establishment of
an LSP related the establishment of the media channel and effective
frequency slot.

In this context, when used unqualified, the frequency slot is a local
term, which applies at each hop. An effective frequency slot applies
at the media chall (LSP) level

A "service" request is characterized as a minimum, by its required
effective slot width. This does not preclude that the request may
add additional constraints such as imposing also the nominal central
frequency. A given frequency slot is requested for the media channel
say, with the Path message. Regardless of the actual encoding, the
Path message sender descriptor sender_tspec shall specify a minimum
frequency slot width that needs to be fulfilled.

In order to allocate a proper effective frequency slot for a LSP, the
signaling should specify its required slot width.

An effective frequency slot must equally be described in terms of a
central nominal frequency and its slot width (in terms of usable
spectrum of the effective frequency slot). That is, one must be able
to obtain an end-to-end equivalent n and m parameters. We refer to
this as the "effective frequency slot of the media channel/LSP must

be valid".

In GMPLS the requested effective frequency slot is represented to the
TSpec and the effective frequency slot is mapped to the FlowSpec.

The switched element corresponds in GMPLS to the 'label'. As in
flexi-grid the switched element is a frequency slot, the label
represents a frequency slot. Consequently, the label in flexi-grid
must convey the necessary information to obtain the frequency slot
characteristics (i.e, center and width, the n and m parameters). The
frequency slot is locally identified by the label

The local frequency slot may change at each hop, typically given
hardware constraints (e.g. a given node cannot support the finest
granularity). Locally n and m may change. As long as a given
downstream node allocates enough optical spectrum, m can be different
along the path. This covers the issue where concrete media matrices
can have different slot width granularities. Such "local" m will
appear in the allocated label that encodes the frequency slot as well
as the flow descriptor flowspec.

Different modes are considered: RSA with explicit label control , and
for R+DSA, the GMPLS signaling procedure is similar to the one
described in section 4.1.3 of [RFC6163] except that the label set
should specify the available nominal central frequencies that meet
the slot width requirement of the LSP. The intermediate nodes can
collect the acceptable central frequencies that meet the slot width
requirement hop by hop. The tail-end node also needs to know the
slot width of a LSP to assign the proper frequency resource.
Compared with [RFC6163], except identifying the resource (i.e., fixed
wavelength for WSON and frequency resource for flexible grids), the
other signaling requirements (e.g., unidirectional or bidirectional,
with or without converters) are the same as WSON described in the
section 6.1 of [RFC6163].

Regarding how a GMPLS control plane can assign n and m, different
cases can apply:

   a) n and m can both change. It is the effective slot what
   matters. Some entity needs to make sure the effective frequency
   slot remains valid.

   b) m can change; n needs to be the same along the path. This
   ensures that the nominal central frequency stays the same.

   c) n and m need to be the same.

d)n can change, m needs to be the same.

In consequence, an entity such as a PCE can make sure that the n and m stay the same along the path. Any constraint (including frequency slot and width granularities) is taken into account during path computation. alternatively, A PCE (or a source node) can compute a path and the actual frequency slot assignment is done, for example, with a distributed (signaling) procedure:

Each downstream node ensures that m is >= requested_m.

Since a downstream node cannot foresee what an upstream node will allocate in turn, a way we can ensure that the effective frequency slot is valid is then by ensuring that the same "n" is allocated. By forcing the same n, we avoid cases where the effective frequency slot of the media channel is invalid (that is, the resulting frequency slot cannot be described by its n and m parameters).

Maybe this is a too hard restriction, since a node (or even a centralized/combined RSA entity) can make sure that the resulting end to end (effective) frequency slot is valid, even if n is different locally. That means, the effective (end to end) frequency slot that characterizes the media channel is one and determined by its n and m, but are logical, in the sense that they are the result of the intersection of local (filters) freq slots which may have different freq. slots

For Figure Figure 15 the effective slot is valid by ensuring that the minimum m is greater than the requested m. The effective slot (intersection) is the lowest m (bottleneck).

For Figure Figure 16 the effective slot is valid by ensuring that it is valid at each hop in the upstream direction. The intersection needs to be computed. Invalid slots could result otherwise.

```
            |Path(m_req)     |                  ^              |
            |--------->      |                  #              |
            |                |                  #              ^
         -^---------------^-----------------#----------------#--
Effective #              #                  #                #
FS n, m   # . . . . . . .#. . . . . . . . . # . . . . . . . .# <-fixed
          #              #                  #                #   n
         -v---------------v-----------------#----------------#---
          |              |                  #                v
          |              |                  #        Resv    |
          |              |                  v      <------    |
          |              |                  | flowspec(n, m_a)|
          |              |        <--------|                  |
          |              |     flowspec (n,  |
          |      <--------|          min(m_a, m_b))
              flowspec (n,  |
                 min(m_a, m_b, m_c))
```

Figure 15: Distributed allocation with different m and same n

```
            |Path(m_req)     ^                  |
            |--------->      #                  |              |
            |               #                  ^              ^
         -^---------------#-----------------#----------------#----------
Effective #              #                  #                #
FS n, m   #              #                  #                #
          #              #                  #                #
         -v---------------v-----------------#----------------#----------
          |              |                  #                v
          |              |                  #        Resv    |
          |              |                  v      <------    |
          |              |                  |flowspec(n_a, m_a)
          |              |        <--------|                  |
          |              |     flowspec (FSb [intersect] FSa)
          |      <--------|
              flowspec ([intersect] FSa,FSb,FSc)
```
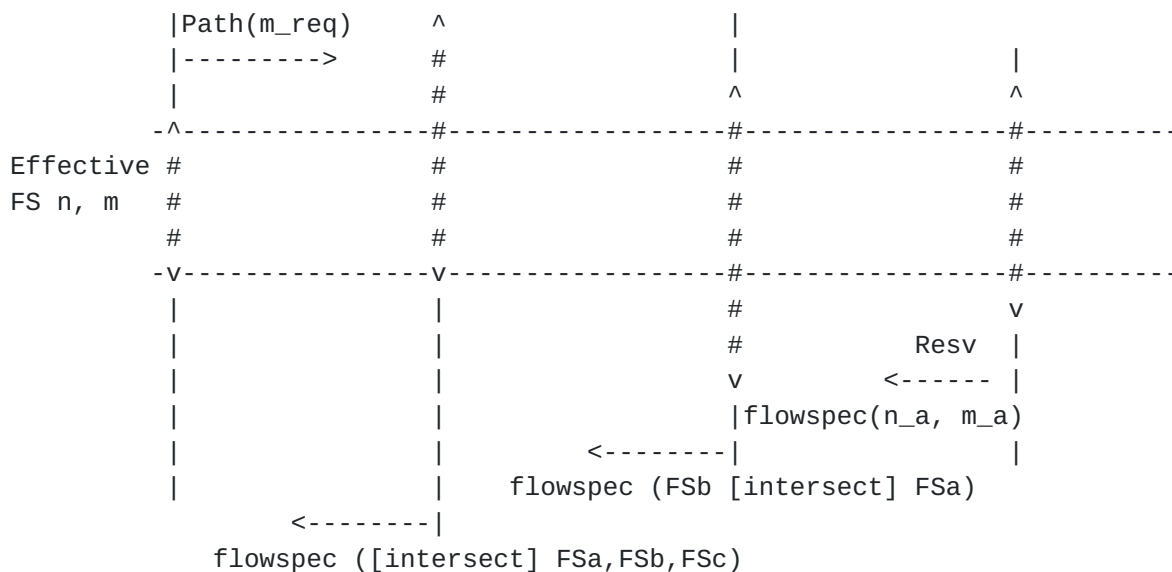
Figure 16: Distributed allocation with different m and different n

   Note, when a media channel is bound to one OCh-P (i.e is a Network
   media channel), the EFS must be the one of the Och-P. The media
   channel setup by the LSP may contains the EFS of the network media
   channel EFS. This is an endpoint property, the egress and ingress
   SHOULD constrain the EFS to Och-P EFS [q: can't the endpoint be

configured based on the final allocation? constraint or output?].

Also note that the case d) applies for one cannot assume that m =
m_requested. If m = m_requested, one cannot ensure that the
effective slot is valid unless all n are equal but, more generically,
different n and same m can be possible, provided that the
intersection of the two most distant local slots is >= requested
width. (See figure below, in the case where m = mreq then -> nb =
na).

```
0 1 2 3 4 ...
|<-------2m---------->|
|--------na-----------|

---------X---------------X------------

            |----------nb--------|
            |<-------2m--------->|
------------------------------------
            |<2mreq>|

(na + m) - (nb - m) >= 2mreq  where nb >= na
(nb - na) <= 2(m - mreq)
```
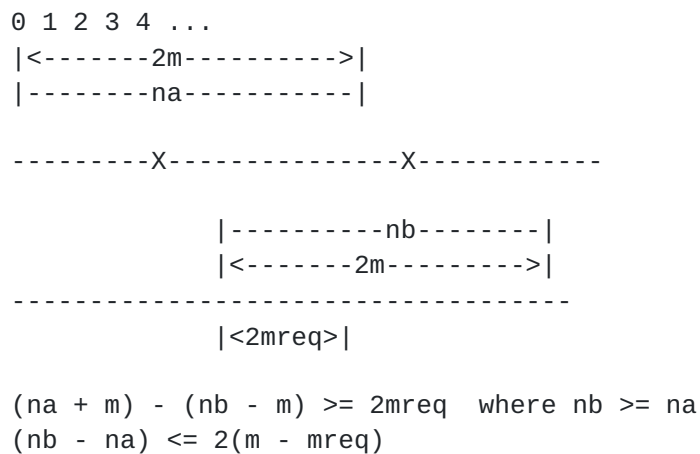
Figure 17: Valid frequency slot case d)

[cyrils' summary of key aspects:

   the label is local and represent the local frequency slot.

   the requested FS is mapped to the TSPec, it may differ from the
   labels, (so likely to carry n and m) .

   the effective FS needs to be known at ingress, the following
   protocol mechanism could be used: label recording, flowspec
   (ADSpec?)

8.2. Neighbor Discovery and Link Property Correlation

[Editors' note: text from draft-li-ccamp-grid-property-lmp-01]

Potential interworking problems between fixed-grid DWDM and flexible-
grid DWDM nodes, may appear. Additionally, even two flexible-grid
optical nodes may have different grid properties, leading to link
property conflict.

Devices or applications that make use of the flexible-grid may not be

able to support every possible slot width. In other words,
applications may be defined where different grid granularity can be
supported. Taking node F as an example, an application could be
defined where the nominal central frequency granularity is 12.5 GHz
requiring slot widths being multiple of 25 GHz. Therefore the link
between two optical nodes with different grid granularity must be
configured to align with the larger of both granularities. Besides,
different nodes may have different slot width tuning ranges.

In summary, in a DWDM Link between two nodes, at least the following
properties should be negotiated:

   Grid capability (channel spacing) - Between fixed-grid and
   flexible-grid nodes.

   Grid granularity - Between two flexible-grid nodes.

   Slot width tuning range - Between two flexible-grid nodes.

8.3. Path Computation / Routing and Spectrum Assignment (RSA)

Much like in WSON, in which if there is no (available) wavelength
converters in an optical network, an LSP is subject to the
''wavelength continuity constraint'' (see section 4 of [RFC6163]), if
the capability of shifting or converting an allocated frequency slot,
the LSP is subject to the Optical ''Spectrum Continuity Constraint''.

Because of the limited availability of wavelength/spectrum converters
(sparse translucent optical network) the wavelength/spectrum
continuity constraint should always be considered. When available,
information regarding spectrum conversion capabilities at the optical
nodes may be used by RSA mechanisms.

The RSA process determines a route and frequency slot for a LSP.
Hence, when a route is computed the spectrum assignment process (SA)
should determine the central frequency and slot width based on the
slot width and available central frequencies information of the
transmitter and receiver, and the available frequency ranges
information and available slot width ranges of the links that the
route traverses.

8.3.1. Architectural Approaches to RSA

Similar to RWA for fixed grids, different ways of performing RSA in
conjunction with the control plane can be considered. The approaches
included in this document are provided for reference purposes only;
other possible options could also be deployed.

8.3.1.1. **Combined RSA (R&SA)**

   In this case, a computation entity performs both routing and
   frequency slot assignment. The computation entity should have the
   detailed network information, e.g. connectivity topology constructed
   by nodes/links information, available frequency ranges on each link,
   node capabilities, etc.

   The computation entity could reside either on a PCE or the ingress
   node.

8.3.1.2. **Separated RSA (R+SA)**

   In this case, routing computation and frequency slot assignment are
   performed by different entities. The first entity computes the
   routes and provides them to the second entity; the second entity
   assigns the frequency slot.

   The first entity should get the connectivity topology to compute the
   proper routes; the second entity should get the available frequency
   ranges of the links and nodes' capabilities information to assign the
   spectrum.

8.3.1.3.   **Routing and Distributed SA (R+DSA)**

   In this case, one entity computes the route but the frequency slot
   assignment is performed hop-by-hop in a distributed way along the
   route. The available central frequencies which meet the spectrum
   continuity constraint should be collected hop by hop along the route.
   This procedure can be implemented by the GMPLS signaling protocol.

8.4. **Routing / Topology dissemination**

   In the case of combined RSA architecture, the computation entity
   needs to get the detailed network information, i.e. connectivity
   topology, node capabilities and available frequency ranges of the
   links. Route computation is performed based on the connectivity
   topology and node capabilities; spectrum assignment is performed
   based on the available frequency ranges of the links [Editors note:
   alternatively, it can based the available media channels] . The
   computation entity may get the detailed network information by the
   GMPLS routing protocol. Compared with [RFC6163], except wavelength-
   specific availability information, the connectivity topology and node
   capabilities are the same as WSON, which can be advertised by GMPLS
   routing protocol (refer to section 6.2 of [RFC6163]. This section
   analyses the necessary changes on link information brought by
   flexible grids.

8.4.1. Available Frequency Ranges/slots of DWDM Links

   In the case of flexible grids, channel central frequencies span from
   193.1 THz towards both ends of the C band spectrum with 6.25 GHz
   granularity. Different LSPs could make use of different slot widths
   on the same link. Hence, the available frequency ranges should be
   advertised.

8.4.2. Available Slot Width Ranges of DWDM Links

   The available slot width ranges needs to be advertised, in
   combination with the Available frequency ranges, in order to verify
   whether a LSP with a given slot width can be set up or not; this is
   is constrained by the available slot width ranges of the media matrix
   Depending on the availability of the slot width ranges, it is
   possible to allocate more spectrum than strictly needed by the LSP.

8.4.3. Spectrum Management

   [Editors' note: the part on the hierarchy of the optical spectrum
   could be confusing, we can discuss it]. The total available spectrum
   on a fiber could be described as a resource that can be divided by a
   media device into a set of Frequency Slots. In terms of managing
   spectrum, it is necessary to be able to speak about different
   granularities of managed spectrum. For example, a part of the
   spectrum could be assigned to a third party to manage. This need to
   partition creates the impression that spectrum is a hierarchy in view
   of Management and Control Plane. The hierarchy is created within a
   management system, and it is an access right hierarchy only. It is a
   management hierarchy without any actual resource hierarchy within
   fiber. The end of fiber is a link end and presents a fiber port
   which represents all of spectrum available on the fiber. Each
   spectrum allocation appears as Link Channel Port (i.e., frequency
   slot port) within fiber.

8.4.4. Information Model

   Fixed DM grids can also be described via suitable choices of slots in
   a flexible DWDM grid. However, devices or applications that make use
   of the flexible grid may not be capable of supporting every possible
   slot width or central frequency position. Following is the
   definition of information model, not intended to limit any IGP
   encoding implementation. For example, information required for
   routing/path selection may be the set of available nominal central
   frequencies from which a frequency slot of the required width can be
   allocated. A convenient encoding for this information (may be as a
   frequency slot or sets of contiguous slices) is further study in IGP
   encoding document.

```
[Editor's note: to be discussed]

<Available Spectrum in Fiber for frequency slot> ::=
    <Available Frequency Range-List>
    <Available Central Frequency Granularity >
    <Available Slot Width Granularity>
    <Minimal Slot Width>
    <Maximal Slot Width>

<Available Frequency Range-List> ::=
    <Available Frequency Range >[< Available Frequency Range-List>]

<Available Frequency Range >::=
  <Start Spectrum Position><End Spectrum Position> |
  <Sets of contiguous slices>

<Available Central Frequency Granularity> ::= n x 6.25GHz,
  where n is positive integer, such as 6.25GHz, 12.5GHz, 25GHz, 50GHz
  or 100GHz

<Available Slot Width Granularity> ::= m x 12.5GHz,
  where m is positive integer

<Minimal Slot Width> ::= j x 12.5GHz,
  j is a positive integer

<Maximal Slot Width> ::= k x 12.5GHz,
    k is a positive integer (k >= j)
```

Figure 18: Routing Information model

8.5. Signaling requirements

8.5.1. Relationship with MRN/MLN

8.5.1.1. OCh Layer

8.5.1.2. Media (frequency slot) layer

9. Control Plane Procedures

FFS. Postpone procedures such as resizing existing LSP(s) without
deletion, which refers to increase or decrease of slot width value
'm' without changing the value of 'n', etc. until requirements have
been identified. At present no hitless resizing protocol has been
defined for OCh. Hitless resizing is defined for an ODU entity only.

10. Backwards (fixed-grid) compatibility, and WSON interworking

   A SSON (network) refers to the GMPLS control of flexi-grid enabled
   DWDM optical networks and it encompasses both the signal and media
   layers. The WSON also encompasses the signal and media layers but,
   since there is no formal separation between OCh and OCC (1:1) this
   layer separation is often not considered. A WSON is a particular
   case of SSON in the which all slot widths are equal and depend on the
   channel spacing. In other words, since there is only a 1:1
   relationship between OCh : OCC there is no need to have separate
   controlled layers, as if both layers are collapsed into one.

```
+======================================+
|      WSON          |         SSON         |
+======================================+
|      OCh           |         OCh          | Signal Layer
+------------------+--------------------+
|                    | Frequency Slot     |
| Optical Channel  |                      | Media Layer
| Carrier          |                      |
+------------------+--------------------+
|      1:1           |        N:1           | Relationship
| single layer     |      MRN/MLN         |  SL : ML
|    network       |       (* TBD)        |
+------------------+--------------------+
```

                   Figure 19: Table Comparison WSON/SSON

   o SSON as evolution of WSON, same LSC, different Swcap?

   o Potential problems with having the same swcap but the label format
      changes w.r.t. wson

   o A new SwCap may need to be defined, LSC swcap already defined ISCD
      which can not be modified

   o Role of LSP encoding type?

   o Notion of hierarchy? There is no notion of hierarchy between WSON
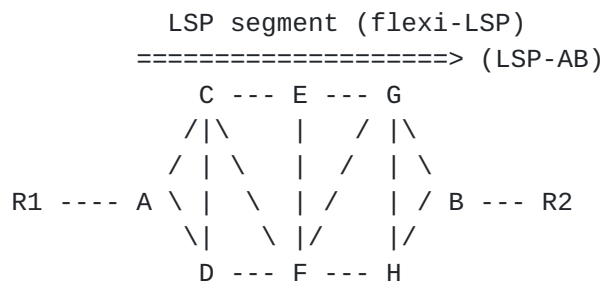   and flexi-grid / SSON - only interop / interwork.

   Arguments for LSC switching capability

   [QW] A LSP for an optical signal which has a bandwidth of 50GHz
   passes through both a fixed grid network and a flexible grid network.
   We assume that no OEOs exist in the LSP, so both the fixed grid path
   and flexible grid path occupy 50GHz. From the perspective of data
   plane, there is no change of the signal and no multiplexing when the

fixed grid path interconnects with flexible grid path. From this
scenario we can conclude that both fixed grid network path and
flexible grid network path belong to the same layer. No notion of
hierarchy exists between them.

[QW] stitching LSP which is described in [RFC5150] can be applied in
one layer. LSP hierarchy allows more than one LSP to be mapped to an
H-LSP, but in case of S-LSP, at most one LSP may be associated with
an S-LSP. This is similar to the scenario of interconnection between
fixed grid LSP and flexible grid LSP. Similar to an H-LSP, an S-LSP
could be managed and advertised, although it is not required, as a TE
link, either in the same TE domain as it was provisioned or a
different one. Path setup procedure of stitching LSP can be applied
in the scenario of interconnection between fixed grid path and
flexible grid path.

```
          e2e LSP
          ++++++++++++++++++++++++++++++++++++> (LSP1-2)

                  LSP segment (flexi-LSP)
                 ====================> (LSP-AB)
                  C --- E --- G
                 /|\      |    / |\
                / | \     |   /  | \
      R1 ---- A \ |  \  | /   | / B --- R2
                \|   \ |/     |/
                 D --- F --- H

     fixed grid --A-- flexi-grid    --B-- fixed grid
```

       Figure 20: LSP Stitching [RFC5150] and relationship with fixed-flexi

11. Misc & Summary of open Issues [To be removed at later versions]

   o Will reuse a lot of work / procedures / encodings defined in the
      context of WSON

   o At data rates of GBps / TBps, encoding bandwidths with bytes per
      second unit and IEEE 32-bit floating may be problematic / non
      scalable.

   o Bandwidth fields not relevant since there is not a 1-to-1 mapping
      between bps and Hz, since it depends on the modulation format,
      fec, either there is an agreement on assuming best / worst case
      modulations and spectral efficiency.

o Label I: "m" is inherent part of the label, part of the switching,
   allows encode the "lightpath" in a ERO using Explicit Label
   Control, Still maintains that feature a cross-connect is defined
   by the tuple (port-in, label-in, port-out, label-out), allows a
   kind-of "best effort LSP"

o Label II: "m" is not part of the label but of the TSPEC, neds to
   be in the TSPEC to decouple client signal traffic specification
   and management of the optical spectrum, having in both places is
   redundant and open to incoherences, extra error checking.

o Label III: both, It reflects both the concept of resource request
   allocation / reservation and the concept of being inherent part of
   the switching.

[12]. Security Considerations

   TBD

[13]. Contributing Authors

   Qilei Wang
   ZTE
   Ruanjian Avenue, Nanjing, China
   wang.qilei@zte.com.cn

   Malcolm Betts
   ZTE
   malcolm.betts@zte.com.cn

   Xian Zhang
   Huawei
   zhang.xian@huawei.com

   Cyril Margaria
   Nokia Siemens Networks
   St Martin Strasse 76, Munich, 81541, Germany
   +49 89 5159 16934
   cyril.margaria@nsn.com

   Sergio Belotti
   Alcatel Lucent
   Optics CTO
   Via Trento 30 20059 Vimercate (Milano) Italy
   +39 039 6863033
   sergio.belotti@alcatel-lucent.com

Yao Li
Nanjing University
wsliguotou@hotmail.com

Fei Zhang
ZTE
Zijinghua Road, Nanjing, China
zhang.fei3@zte.com.cn

Lei Wang
ZTE
East Huayuan Road, Haidian district, Beijing, China
wang.lei131@zte.com.cn

Guoying Zhang
China Academy of Telecom Research
No.52 Huayuan Bei Road, Beijing, China
zhangguoying@ritt.cn

Takehiro Tsuritani
KDDI R&D Laboratories Inc.
2-1-15 Ohara, Fujimino, Saitama, Japan
tsuri@kddilabs.jp

Lei Liu
KDDI R&D Laboratories Inc.
2-1-15 Ohara, Fujimino, Saitama, Japan
le-liu@kddilabs.jp

Eve Varma
Alcatel-Lucent
+1 732 239 7656
eve.varma@alcatel-lucent.com

Young Lee
Huawei

Jianrui Han
Huawei

Sharfuddin Syed
Infinera

Rajan Rao
Infinera

Marco Sosa
Infinera

Biao Lu
Infinera

Abinder Dhillon
Infinera

Felipe Jimenez Arribas
Telefonica I+D

Andrew G. Malis
Verizon

Adrian Farrel
Old Dog Consulting

Daniel King
Old Dog Consulting

Huub van Helvoort

14. Acknowledgments

The authors would like to thank Pete Anslow for his insights and
clarifications.

15. References

15.1. Normative References

   [G.709]   International Telecomunications Union, "ITU-T
              Recommendation G.709: Interfaces for the Optical Transport
              Network (OTN).", March 2009.

   [G.800]   International Telecomunications Union, "ITU-T
              Recommendation G.800: Unified functional architecture of
              transport networks.", February 2012.

   [G.805]   International Telecomunications Union, "ITU-T
              Recommendation G.805: Generic functional architecture of
              transport networks.", March 2000.

   [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
              Requirement Levels", BCP 14, RFC 2119, March 1997.

   [RFC3945] Mannie, E., "Generalized Multi-Protocol Label Switching
              (GMPLS) Architecture", RFC 3945, October 2004.

   [RFC4206] Kompella, K. and Y. Rekhter, "Label Switched Paths (LSP)
              Hierarchy with Generalized Multi-Protocol Label Switching
              (GMPLS) Traffic Engineering (TE)", RFC 4206, October 2005.

   [RFC5150] Ayyangar, A., Kompella, K., Vasseur, JP., and A. Farrel,
              "Label Switched Path Stitching with Generalized
              Multiprotocol Label Switching Traffic Engineering (GMPLS
              TE)", RFC 5150, February 2008.

   [RFC6163] Lee, Y., Bernstein, G., and W. Imajuku, "Framework for
              GMPLS and Path Computation Element (PCE) Control of
              Wavelength Switched Optical Networks (WSONs)", RFC 6163,
              April 2011.

15.2. Informative References

   [G.694.1] International Telecomunications Union, "ITU-T
              Recommendation G.694.1, Spectral grids for WDM
              applications: DWDM frequency grid, draft v1.6 2011/12",
              2011.

   [G.872]   International Telecomunications Union, "ITU-T
              Recommendation G.872, Architecture of optical transport
              networks, draft v0.16 2012/09 (for discussion)", 2012.

   [RFC4397] Bryskin, I. and A. Farrel, "A Lexicography for the
              Interpretation of Generalized Multiprotocol Label
              Switching (GMPLS) Terminology within the Context of the
              ITU-T's Automatically Switched Optical Network (ASON)
              Architecture", RFC 4397, February 2006.

   [WD12R2]   International Telecomunications Union, WD12R2, Q12-SG15,
              ZTE, Ciena WP3, "Proposed media layer terminology for
              G.872", 05 2012.

Authors' Addresses

   Oscar Gonzalez de Dios (editor)
   Telefonica I+D
   Don Ramon de la Cruz 82-84
   Madrid,   28045
   Spain

   Phone: +34913128832
   Email: ogondio@tid.es

Ramon Casellas (editor)
CTTC
Av. Carl Friedrich Gauss n.7
Castelldefels,   Barcelona
Spain

Phone: +34 93 645 29 00
Email: ramon.casellas@cttc.es

Fatai Zhang
Huawei
Huawei Base, Bantian, Longgang District
Shenzhen,   518129
China

Phone: +86-755-28972912
Email: zhangfatai@huawei.com

Xihua Fu
ZTE
Ruanjian Avenue
Nanjing,
China

Email: fu.xihua@zte.com.cn

Daniele Ceccarelli
Ericsson
Via Calda 5
Genova,
Italy

Phone: +39 010 600 2512
Email: daniele.ceccarelli@ericsson.com

Iftekhar Hussain
Infinera
140 Caspian Ct.
Sunnyvale,   94089
USA

Phone: 408-572-5233
Email: ihussain@infinera.com